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Structure Behaviour Analysis and Detection of Errors Made at the Design Stage

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Abstract. The reconstruction of public buildings is one of the most important fields of construction engineering. Reconstruction works allow not only increasing the service life of buildings, but also improving the quality of premises, equipping buildings with more advanced utility equipment, enhancing the architectural appearance of buildings, and increasing their energy efficiency. An individual approach to the development of reconstruction methods and procedures shall be taken for buildings built in different years. Furthermore, when developing a reconstruction project it is very important to use actual versions of relevant normative documents and consider the effect of structures being installed on the main load-bearing structures of a reconstructed building. It is also necessary to analyze the influence of new structures on the existing structures of the building. This work contains the analysis of behavior of reconstructed roofed market structures. Errors made during the reconstruction are highlighted. The results of analyses are described and the conclusion regarding the load-bearing capacity of the reconstructed building framework is given.

1. Introduction

The reconstruction of public buildings is one of the most important fields of civil engineering. Buildings can be reconstructed not only to eliminate the wearing of their load-bearing structures, but also to enhance the quality of premises, install new utility equipment, improve the architectural appearance of a building or modernize it, or to increase the energy efficiency of a building. An individual approach to every project is of vital importance for the reconstruction purpose. Before commencing the design works it is necessary to conduct a comprehensive examination of the utility systems, equipment, and load-bearing structures of the building. Basing on the results of the examination it is possible to determine the tentative scope of works to be carried-out under the reconstruction project, and commence the project development. When developing a reconstruction project, it is necessary to carry-out several analyses of individual load-bearing structures of the building, and of the whole building as well, because the partial replacement of the bearing structures may cause not only the increase in the design loads on the building framework, but also change the load distribution diagram[1-3].

In this work we present the survey of a Vostochnyi roofed market building (figure 1) in Chelyabinsk. After the reconstruction of this building it became necessary to conduct a survey and the analysis of the behavior of its load-bearing structures. These works were carried-out by the specialists of Institute of Civil Engineering and Architecture of Urals Federal University (CEIA UrFU) and designers of TECHCON Ltd. Several errors made during the reconstruction were revealed by the abovementioned survey.

Figure 1. Structural module, Vostochnyi roofed market.

2. Survey and analysis of bearing structures of reconstructed Vostochnyi roofed market building

The surveyed structure consists of six spaced preassembled structural modules "Module-6" (30x30 meters each, see the figure 2) with 3x3 meter mesh.

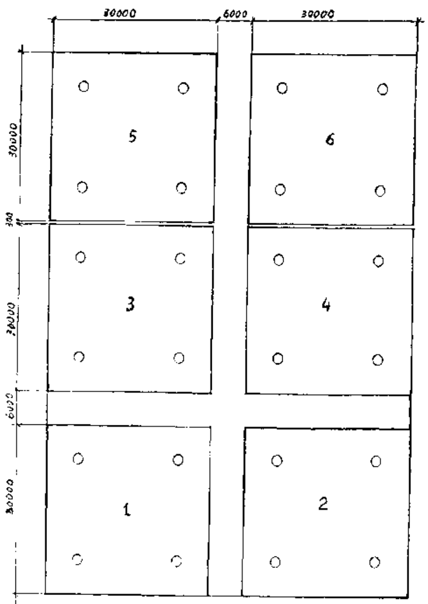

Figure 2. 2 Layout of preassembled structural modules.

During the construction of the building, structural modules "Kislovodsk" with load-bearing capacity of 300 kgf/m2 were replaced with four 320 kgf/m2 modules (modules No. 1 to 4) and two 400 kgf/m2 modules (No. 5 and 6). The structural modules are supported by tubular steel columns which are rigidly connected to the foundations (figure 3).

The roofing of the structural modules is made of steel sheeting. Arch skylight structures are covered with a translucent material "Ondex ecolux".

Figure 3. Column.

Initially, spaces between the modules were covered with separate light arched structures. During the use of the building, arch skylights with 9 meter span have been installed in these spaces (figure 4). Two independent structures were created as a result. Structural modules 1 – 4 have their edges connected by arch skylights forming a "cross" and are connected in the center with a "valley" structure which is also an arch skylight. The latter have caused an excessive loading condition resulting in deformation of individual structural components.

The examination of the roofed market reconstruction project revealed that the assessment of influence of the arch skylights on the whole structure was not included in the analysis of arch skylight supporting conditions. It is worth mentioning that the typical design of such structures does not provide for any structures resting on their edges. Besides that, it shall be noted that previous surveys included the analysis of separate structural modules taking into account the rigidity of a roof sheeting placed on the beams of top chords of the modules. The survey of the roof sheeting condition showed that its bolted connections have become loose thus making it not reasonable to consider the influence of the roof sheeting on the rigidity of the top chords of structural modules.

A geodetic survey of the positions of the structural module bottom chord points and the arch skylights showed that the skylight structures resting on the bottom chord of the structural modules causes a significant influence.

Figure 4. Arched structures of skylights resting on the bottom chords of structural modules.

The on-site examination of the load-bearing structures of the structural modules and the analysis of available technical documents revealed that:

- The condition of the load-bearing structures of the roof has not been surveyed since 2001.

- The materials of the previous surveys and design documents presented did not include the analysis of the load-bearing capacity of roof structures taking into account the "cross" and "valley" steel structures resting on the roof structural modules.

However, the "cross" and "valley" structures resting on the bottom chord joints of the structural modules create an uniform multiple indeterminate three-dimensional system which, combined with the normative increase in the snow load and creation of additional snow pockets, causes the overstress of individual elements of the structural modules. In order to verify these assumptions it was decided to conduct the analysis of behavior of the structural modules and the arch skylights.

The analysis of the assumed elastic behavior of the structure was carried-out using LIRA and SCAD software. Two simulation models were created: one for the structural modules from 1 to 4 (figure 5), and the other for the modules 5 and 6 (figure 6) [4-8]. The columns were adopted as being fixed in the foundations. The rod elements of the structural modules were represented by space truss finite elements, and "cross" and "valley" structure elements were represented by space frame finite elements.

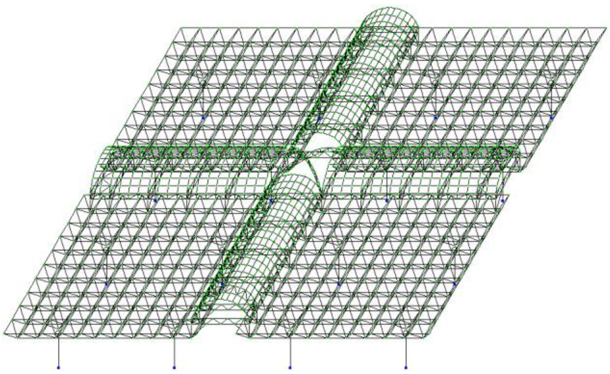

Figure 5. Model of structural modules 1 – 4 with "cross" and "valley" structures.

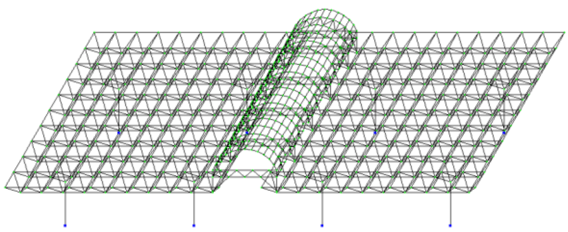

Figure 6. Model of structural modules 5 and 6.

The linear elastic analysis of the structural modules and skylights joint behavior showed that overstress (up to 50%) of individual elements of the structural modules occurs in the snow pocket areas. Figures 7 and 8 show the elements of the structural modules 1 – 6 for which the required strength and stability parameters were exceeded. The figure 9 shows the strained shape of the modules.

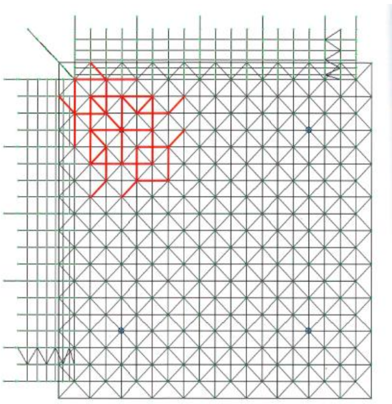

Figure 7. Location of overstrained elements of the structural modules 1 to 4. The elements are located in the corner adjacent to the "cross".

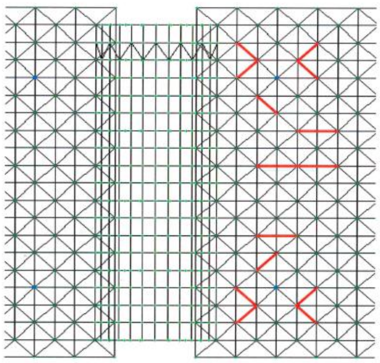

Figure 8. Location of overstrained elements of the structural modules 5 and 6. The elements are located in areas adjacent to the skylights.

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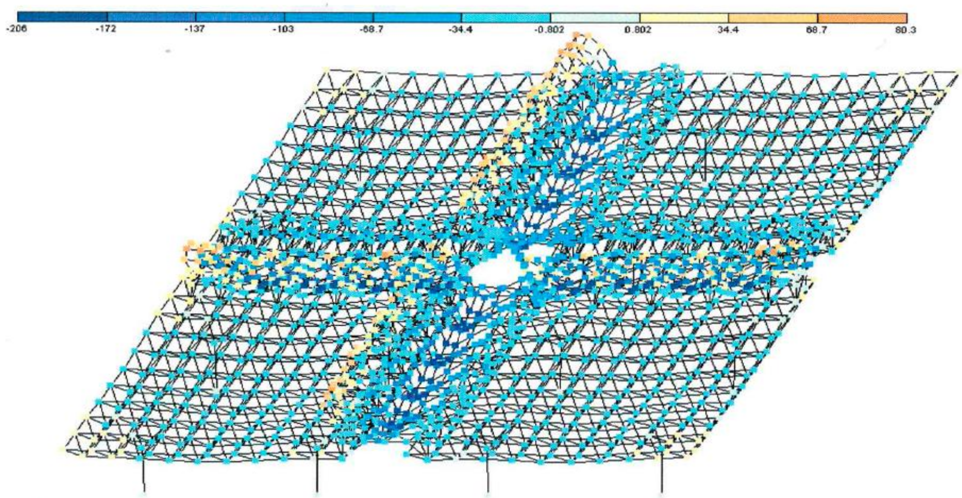

Figure 9. Spatial pattern of displacement of the simulation model joints under the design dangerous load. The scale of displacement in mm is given on top of the picture.

Before the reconstruction the building had an open layout. During the reconstruction, enveloping structures were erected, but the analysis of temperature differential effect was omitted [9-10].

The analysis of seasonal temperature effect was performed taking into account that the skylight structures resting on the structural modules form a multiple indeterminate system. In that case a strain shall arise due to seasonal cooling (heating) of the structural elements. As an example, the figure 10 shows a spatial pattern of displacement of the elements of modules 5 and 6 caused by uniform heating of the elements by 20°C. Maximum displacement of the joints along the long side of the model is 8 mm, along the short side of the model is 3.8 mm, and in vertical direction is 3.4 mm. Maximum longitudinal compression force in the elements is 0.3 ton-force.

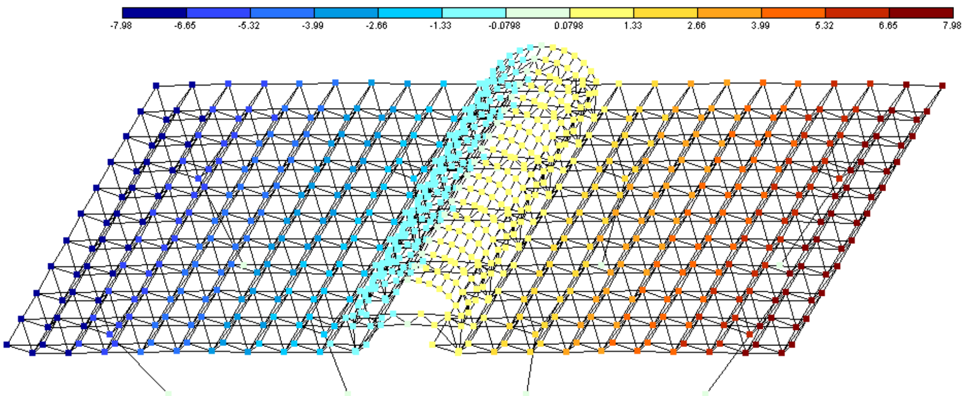

Figure 10. Displacement of the joints of the simulated modules 5 and 6 caused by uniform heating of their elements by 20°C. The scale of displacement in mm is given on top.

3. Conclusion

When developing a reconstruction project it is necessary to conduct several calculations for individual load-bearing elements of the building structure and for the whole building as well. The results of the survey of Vostochnyi market building, carried-out by the specialists of Institute of Civil Engineering and Architecture of Urals Federal University and designers of TECHCON Ltd, showed that the modification of the roof structures caused not only the increase in the design load on the load-bearing

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elements, but also changed the load-distribution pattern diagram of the whole building. The analysis of the elastic behavior of the structural modules and skylight structures revealed that some elements of the structural modules are subject to significant overstrain (up to 50%) in snow pocket areas. Besides that, it was found that at the initial reconstruction stage the temperature effect analysis was omitted. In the result of this omission, the displacement of structural joints caused by seasonal cooling and heating was completely ignored. In general, the analyses conducted show that the application of full design load to the roof of the roofed market may cause a failure. It is necessary to pay special attention to maintaining the loading diagram of the structure when carrying-out reconstruction works, and thoroughly justify any changes introduced to this diagram.

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